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AI-Driven 6G Networks: Evolution, Security Challenges, and Future Directions

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ABSTRACT

The advancements in mobile networks over the generations have been remarkable, with broad improvements typically observed for each generation. As we begin to transition into the 6G era, it will be important to see what technologies, applications, and challenges mold this new state of connectivity. This paper explores the journey from AI-centric 6G networks, work being done to secure them, technology matters, and recommendations for future research on 6 G. 6G has the potential to change the future state in many industries including smart cities, self-driving, virtual reality, gaming, health care, industrial automation, and UAV communication. But, 6G deployment will involve risk to security related to vulnerabilities in architecture, data privacy, and security issues we may not yet know. Possible technological solutions explored will focus on post-quantum cryptography (public-key algorithms), blockchain authentication, hierarchical security models, and standardized electronic network security protocols. Major 6 G-denoting technologies we see used include terahertz communication, ultra-massive MIMO, beamforming, cell-free massive MIMO, millimeter waves, reconfigurable intelligent surfaces, quantum communication, and UAV/satellite networks. Future work will include high-frequency communication, AI network management, efficient hardware, and secure encryptions like quantum key distribution (QKD). This survey offers a comprehensive and explicit perspective on the promise of AI-enabled 6G wireless communication networks.

KEYWORDS: *AI-Driven Networks, 6G, Security Challenges, Key Technologies, Evolution from 1G to 6G, Applications, Future Research Directions.*

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1. INTRODUCTION

In this paper, we discuss the development of AI-driven 6G networks from the perspective of their security challenges, key enabling technologies, and future research perspectives. 6G networks will be enhanced levels of connectivity, speed, and reliability, thus enabling a range of applications, including smart cities, autonomous vehicles, virtual reality, online gaming, healthcare delivery, industrial automation, and UAV communication. However, despite the advantages of 6G, there are security risks due to architectural vulnerabilities, emerging technologies and protocols, data privacy and integrity, and continuing/alternative attacks. Strategies for mitigation include post-quantum cryptography, blockchain authentication, hierarchical security models, and collaborative standardization. Key enabling technologies for the deployment of 6G will include terahertz communication, ultra-massive MIMO and beamforming, cell-free massive MIMO, millimeter waves, reconfigurable intelligent surfaces (IRS), quantum communication, and UAV/satellite communication. Future research perspectives will focus on: millimeter- and terahertz-wave communication, smart and adaptive protocols, AI-driven congestion management, developing low-power hardware and sustainable networks, post-quantum cryptography and encryption methods using

AI, quantum key distribution, and ultra-reliable low-latency communication.

2. Evolution from 1G to 6G

The mobile communications era began around the early 1980s and has continued to evolve with rapid growth and advancements in the following decades[12]. Mobile wireless technology can be demarcated into clear eras, and each has been a stepping stone to incredible leaps and innovations in data rate, connectivity, and functionality. Since 1980, a new generation of wireless communication networks has emerged every 10 years [9], [10], and now there are 5 generations. Figure 1 discusses the key milestones of the five generations (1G to 5G) of wireless communication networks. Further, here is a brief overview of how wireless technologies are evolving.

1G:-

The first phase of mobile wireless technology, called 1G, was introduced in the early 1980s, using mainly analog technology [12]. 1G was only trusted for voice calls and was characterized by low data speeds and terrible sound quality [13]. Examples of 1G include Advanced Mobile Phone System (AMPS), Total Access Communication System (TACS), and Nordic Mobile Telephone (NMT) [14]. 1G is a straightforward analog system with data speeds up to 2.4 kbps for voice conversations. There is a 30 kHz bandwidth, and frequency modulation (FM) and frequency division multiple access (FDMA) communication technologies are used [12]. 1G also has a lot of drawbacks, like i) due to the analog modulation, there is no encryption and poor quality, and security; ii) limited users because of FDMA technology; iii) unsecured base station power radiation, and lack of transfer procedures; iv) voice services only; v) different systems because of the lack of proper international standards [10]-[12].

2G:-

The start of the second generation (2G) of mobile networks in the early 1990s was a changeover from analog to digital technology [16]. 2G networks debuted many new capabilities in addition to the traditional voice services such as Short Message Service (SMS) and email. Also, 2G networks enhanced the quality of audio and also enhanced security [17]. Some common 2G Mobile networks are GSM (Global System for Mobile Communication), IS-95 (Interim Standard-95), PDC (Personal Digital Cellular), and CDMAone (Code Division Multiple Access). The features of this generation are as follows: i) made a uniform international mobile communication standard, and promoted the development of global mobile communication technology; ii) improved services; improved network security by using encrypted numbers; iv) improved the capacity of the system; and v) battery life of the mobile is longer as the radio is using less power. However, the slow data rate of GSM led to improvements in cellular systems that utilized general packet radio service (GPRS) technology.

3G:-

The advent of 3G (Third Generation) mobile networks in the early 2000s represented a major Improvement in mobile technologies, as they combined voice and data services [18]. These networks delivered greater data transfer capacities and enabled users to browse the Internet on their mobile devices [19]. 3G networks also introduced Multimedia Message Service (MMS) and allowed consumers to access data-intensive applications such as email, web browsing, video streaming, and mobile television [20]. Beyond enhanced data-transmission capacities and web-browsing speed, 3G networks offered greater coverage area and included security features such as packet data confidentiality and integrity. The following are examples of 3G (Third Generation) mobile networks: CDMA2000 (Code Division Multiple Access 2000), WCDMA (Wideband Code Division Multiple Access), and EDGE (Enhanced Data rates for GSM Evolution) [21].

4G:-

The advent of 4G (Fourth Generation) cellular networks in the early 2010s was a significant leap in mobile technology, with the capability to transmit data at extremely high speeds as well as enhanced coverage area [22]. HD video streaming, mobile video conferencing, online gaming, and fast mobile Internet were made possible with these networks. Examples of the 4G (Fourth Generation) mobile networks are LTE (Long-Term Evolution) and WiMAX (Worldwide Interoperability for Microwave Access) [23]. LTE is a wireless access technology based on orthogonal frequency division multiplexing (OFDM) that allows the employment of sophisticated multi-antenna transmission and can have the possibility of transmission over expansion bands of as much as 20 MHz. A significant technology within the system is MIMO, which enables multi-stream and higher data rates, yielding a high spectral efficiency and connection quality, and adjusts the radiation patterns for signal gain and interference mitigation. The external array is created by the antenna's adaptive beam forming. LTE data rates are attainable at mobile speeds of up to 100 megabits per second (Mbps). To meet the massive growth of demands for mobile broadband communications capacity annually, the wireless technology roadmap has been upgraded to

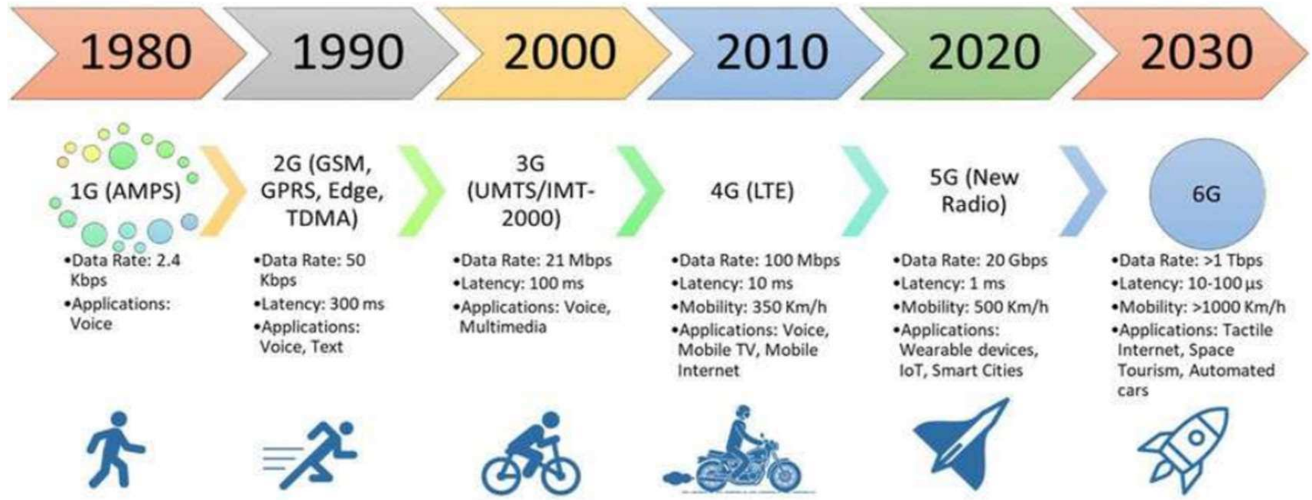
encompass LTE advanced (LTEA) [14], which can support a peak theoretical throughput of more than 1 Gbps.

5G:-

The deployment of 5G (Fifth Generation) mobile networks during the early 2010s is the newest development in mobile technology, with the original 5G mobile networks going live in 2018 (24). The networks are characterized by veritably high pets of data transmission, enhanced network content, and ultra-low latency. 5G networks promise to be a base for the Internet of Things (IoT), smart metropolises, and the fourth industrial revolution (25). The 5G communication standardization process is now complete, and it's being enforced on a global basis (20). The ITU defines the vision and specifications; 5G should meet eight KPI and three common scripts (21). Millions of connections square kilometer (1 M/ km2) massive machine challenge technology in three scripts eMBB Gb/ s data rate, URLLC milliseconds (ms) air interface detention, and massive machine challenge technology in three scripts Indicator type communication (mMTC). Numerous enabling technologies have been developed, considered in standardization, and enforced in specialized trials to achieve these KPIs (2). Binary connectivity armature, massive MIMO, UDN, sophisticated coding and modulation, millimeter-wave dispatches, flexible frame structure, non-orthogonal multiple access, and other wireless technologies are only a many exemplifications (4). As illustrated in Figure 2, the core backbone of the 5G network consists of colorful factors considerably equipped throughout the network, similar asmulti-access edge computing (MEC) data center, coming generation core (NGC), and active antenna system (AAS) (with 5G NR support) Source antenna system) (22). nevertheless, as a result of the massive expansion in the number of associated particulars, the data business has expanded exponentially and can rise to hundreds (s) of bias per m3; away from the sheer boost in new operations, similar as virtual reality/ stoked reality (VR/ AR), independent buses, three-dimensional integrated dispatches, and new apps yet to be conceived (6), they will continue to bear data rates. Will offer advanced and lower quiescence than 5G networks. These are presumed to be the major driving impulses for the fruition of 6G communication systems. Grounded on the colossal eventuality of 5G networks and their probable future elaboration, what should the characteristics of 6G contain that 5G does not? Research, Academia, and industry have banded to describe and determine the crucial qualifying technologies that can characterize 6G; it's anticipated to be rolled out by 2030 (7).

6G:-

Networks are presently being delved and developed as the coming elaboration of mobile networks, with the anticipation of furnishing unequaled transmission pets, ultra-low quiescence, and bettered content (26). These networks will incorporate slice-edge technologies such as terahertz communication, ultra massive MIMO, artificial intelligence, machine literacy, amount communication, millimeter, reconfigurable intelligent shells (27), etc. Implicit operations for 6G networks include linked robotic and tone-governing systems, wireless brain-computer interfaces, blockchain advancements, immersive multi-sensory realities, space and deep-ocean disquisition, tactile internet capabilities, and artificial networking. 6G will be streamlined and enlarged based on the visualization and expansion of 5G to reach up to 100 times the data throughput, advanced system capacity, reduced quiescence, advanced diapason effectiveness, and wider and deeper content. To enable brisk movement, to serve the Internet of Everything (IoE), and to fully promote the elaboration of intelligent life and the artificial universal intelligent mobile society. G should be a comprehensive network with broader and wider content, including terrestrial, satellite, and short-distance device- to- device communication. Thanks to sophisticated mobile operation technologies, 6G can service a wide range of situations, including airspace, land, and ocean, performing in the world's first ubiquitous mobile broadband communication system (25). – To attain a broader bandwidth, 6G is planned to operate at advanced frequencies, similar to millimeter-wave, terahertz (26), and visible light. In comparison to 5G, data rates can be enhanced in 6G by over one hundred times, allowing for the topmost data rate of Tb/ s and a stoner experience data rate of 10 Gb/ s. Likewise, 6G can take advantage of flexible frequency sharing technologies to boost frequency exercise effectiveness indeed more (27).



3. Security Challenges in 6G Networks

3.1. Architectural Weaknesses:-

Light infrastructures like IoT devices and MEC nodes are exposed to physical attacks, exhaustion of resources as well as resources, and insecure communications relying on weak constraints on computational resources. In SDN, the decentralized nature of the control plane can expose opportunities to hijack, for example, the controller, saturation of the switch, or intrusive access to virtual machines. In NFV use of hypervisors can introduce vulnerabilities. Automation powered by AI presents risks for undetected attacks to occur in the automation cycle in the supplied loop or network, especially in microservices like UPMS or CPMS.

3.2. Emerging Technologies and Protocols:-

Threats of Denial-of-Service (DoS) attacks against authentication servers or to leak data, where slices of the networks have been compromised. Utilizing and coupling of the third-party code in open radio access networks expose systems to exploitation of the supply chain and back doors. Cryptography based on classical practices will become useless with the evolution of quantum computing, requiring quantum-safe cryptography to be developed.

3.3. Data Privacy and Integrity:-

Facilities utilizing the Internet of Everything (IoE) networks will be able to collect sensitive data, thereby raising action and ethical concerns, especially if access to the data is unauthorized. The

Omission of good encryption practices and the use of resource-constrained devices has enabled Interception of Terahertz-band communications. Impersonation of a person via AI-generated content that can influence biometric authentication systems and is capable of impersonating a trusted source.

3.4. Continuing and Alternative Attacks:-

Advanced persistent threat (APT) actors can now launch autonomous attacks such as laughable, more adaptable, and large-scale attacks, for example, DDoS, ransomware, or denial of service (DoS), and bypass traditional cyber defenses. Espionage in cyberspace due to greater geopolitical tensions as nation-states tend to coalesce computer-intensive systems, attacking specific critical infrastructure components entirely or parts of supply chain actors leading to increased vulnerability. An alternative state actor in the cyber domain, well-resourced adversaries seeking and mentioning multi-vector infiltration into computer systems, living off the land as they produce undetected threat campaigns.

Mitigation Strategies

- **Post-Quantum Cryptography (PQC):** Implements quantum-resistant algorithms for data encryption.
- **Blockchain Authentication:** Decentralized identity verification prevents unauthorized access.
- **Hierarchical Security Models:** Separate sub-network security from wide-area protocols to limit breach impacts.
- **Collaborative Standardization:** Governments and industries must align on global security frameworks for multivendor interoperability.

Notable Attack Vectors

Attack Type	Description
DDoS/Energy Depletion	Overloading authentication servers or draining device batteries.
Quantum Hacking	Breaks classical encryption using quantum algorithms.
AI Manipulation	Adversarial attacks alter AI behavior in network management.
Illegal RIS Deployment	Rogue reconfigurable intelligent surfaces intercept data transmissions.

4. Applications of 6G Network

4.1. Smart Cities:-

AI-6G convergence will transform the smart city to re-engineer urban living by enhancing infrastructure, public services, and sustainability. AI makes it possible to analyze huge amounts of data in an attempt to control traffic flow, optimize energy consumption, and facilitate public safety through predictive policing. AI also makes it possible to monitor the weather in real time, allowing cities to respond swiftly to changes and challenges. With 6G, which has more capacity, lower latency, increased range, and enhanced security, smart cities will be more advanced. The technology will provide ubiquitous, high-quality connections that can support the increasing demands of connected devices and applications.

4.2. Autonomous-Vehicle Communications:-

Though different levels of autonomy are under test in many countries globally, autonomous vehicles produced in mass volumes seem a distant prospect. Sixth-generation (6G) communications find many applications and are increasingly being used as a new approach to incorporating existing cars and communication technologies into AVs. Autonomous cars and infrastructure networks will have a more accurate or improved interaction in real-time with AI-based 6G networks. From the functionality of efficiency in communication activity, the function of artificial intelligence in 6G networks is especially accountable for real-time routing choice, especially in autonomous automobile navigation [21,22].

4.3. Virtual Reality:-

Sixth-generation (6G) networks, which will be much faster than 5G at approximately 1 terabit per second, will revolutionize virtual and augmented reality (VR and AR) experiences. More speed and bandwidth in 6G, via VR apps, can provide higher resolution, higher frame rate, and faster interaction and hence more compelling and realistic virtual experiences. Apart from being fruitful to gaming and entertainment, it will also play a revolutionary role in healthcare, education, etc. For example, in medicine, VR will facilitate better remote operations and training, and education will have more interactive and immersive learning spaces. With 6G networks' improved tracking and lower latency, users can engage with virtual worlds in a more natural manner, lag-free, and seamlessly traverse virtual spaces. Such unencumbered interaction will make VR and AR experiences more practical and realistic, further boosting the user experience. The combination of AI and 6G will further take the innovation of VR and AR technologies to the next level.

4.4. Online Video Games:-

Social commerce is a critical element of both mobile and metaverse gaming since contemporary videogame players increasingly need real-time communication, bringing to an end face-to-face relations over textbook-based conversation. This has been necessitated by the need for even more immersive and interactive gaming experiences. To enable these real-time connections, gamers need presto, uninterrupted connections, and this is where 5G and 6G technologies fit in. These new cellular networks hold the promise of revolutionary revenues in wireless internet pets, which directly affect the quality of the game. With 6G, the potential for ultra-low quiescence and high bandwidth enables real-time in-game player commerce, i.e., players will be able to converse effortlessly and without delays.

The fast response times made possible by 6G technology will make gaming scripts more natural and perfect, blurring the pace of real-life relationships.

Gaming players will experience more immersive, continuous social gaming, with more lifelike movement, communication, and commerce within virtual worlds. also, 6G allows for more immersive stoked reality (AR) and virtual reality (VR) gests within gaming. With the required speed and minimal quiescence, 6G provides space for the abandonment of AR/VR technology that upgrades gameplay, allowing players to become completely absorbed within virtual worlds. This technology will play a vital role in the next gaming boom as social commerce and integration with the metaverse will be even more interactive and immersive.

4.5. Healthcare Delivery:-

Sixth-generation (6G) networks will transform the provision of health care through their ability to facilitate intricate remote medical procedures, for instance, remote surgery. The doctor will be in a near-future position to operate robotic surgery systems and visualize the point of surgery in real-time, even when patients and medical professionals are miles away from each other. Such an ability will be very applicable in distant or remote regions where specialists are not easily available. The convergence of 6G and AI will propel the establishment of smart healthcare with active monitoring of personal health, tele-diagnosis, and holographic medicine. AI and sensor technologies will facilitate real-time monitoring of patients, enhancing diagnosis and treatment pathways. Telemedicine will be transformed by 6G's high-bandwidth, low-latency to provide better, personalized delivery of healthcare. Remote surgeries will be more precise, and AI will

anticipate disease before it occurs further and making preventive treatment possible.

4.6. Industrial Automation:-

AI and 6G technology integration will transform industrial automation and bring a new era of smart factories. Along with the effectiveness of AI in analyzing huge volumes of data in real-time and the extremely high-speed communications of 6G, factories will be able to reap real-time data analysis to increase production efficiency immensely.

This synergy will allow factories to run at top levels by being able to react quickly to shifts in the manufacturing environment and refine workflows in real-time, resulting in gains in productivity and flexibility. Predictive maintenance will be one of the most effective uses of AI and 6G in industrial automation. With real-time data, AI will be monitoring equipment and machine performance around the clock, identifying problems before they happen.

4.7. UAV Communication:-

Unmanned Aerial Vehicles (UAVs) are classified according to their weight into five classes: micro (less than 100 g), very small (100 g to 2 kg), small (2 to 25 kg), medium (25 to 150 kg), and giant (over 150 kg). Small UAVs are generally used in civilian operations, performing tasks like surveillance, monitoring, and delivery. Conversely, big UAVs are used in mission-critical or defense missions, including reconnaissance, warfare missions, or bulk logistics. Cellular networks, especially 6G, offer crucial support in UAV operations to enable improved inter-drone communication and improve the efficacy and security of their operations. The high-end features of 6G, including ultra-low latency, high data rates, and higher reliability, make it a better choice for UAV networks, particularly in extreme conditions like areas out of the range of direct visual perception. If other communication means are not working in such an area, 6G offers a robust, efficient connection between UAVs that allows them to operate smoothly. The worldwide deployment of IoT supported by 6G will further confirm the role of UAVs in different applications. With 6G, IoT coverage will be greater, and more devices per square kilometer than 5G, which will support operations in areas previously not accessible or blind spots. The high density of IoT devices facilitates the supply of UAVs in monitoring the environment, agriculture, or infrastructure inspection.

Furthermore, 6G's capacity to support many more devices in a specific area guarantees that UAV networks will be able to support large numbers of drones at once. Overall, 6G's strong features will significantly enhance the performance, coverage, and security of UAV operation, making it more efficient and more reliable for a wide range of applications.

5. Key Technologies for 6G Deployment

5.1. Terahertz Communication:-

Terahertz communication provides extremely fast communication, allows for diminished congestion, and facilitates encrypted data transfer. In addition, it offers the potential for high-resolution imaging, remote sensing, and participatory medical processes.

5.2. Ultra-Massive MIMO:-

Using extremely large antenna arrays, ultra-massive MIMO promotes increased data rates, network capacity, and improved efficiency. It also allows for the spectrum to be utilized more efficiently, which would benefit applications in the VR world, smart cities, and autonomous systems.

5.3. Beamforming:-

Beamforming focuses wireless signals so that coverage can be improved, interference can be reduced, and speeds can be increased. It is also suitable for real-time applications such as remote surgery or self-driving cars.

5.4. Cell-Free Massive MIMO:-

Cell-free massive MIMO applies multiple antennas across various regions to promote better coverage, lower latency, and more energy-efficient wireless transmission. In particular, it improves network performance in large, crowded areas, such as stadiums and airports.

5.5. Millimeter Waves (mmWave):-

Operating at very high frequencies, mmWave offers increased speed and network capacity. However, the range associated with mmWave will require more infrastructure and AI-based optimization to ensure a desirable signal continues to provide network services.

5.6. Reconfigurable Intelligent Surfaces (RIS):-

Reconfigurable intelligent surfaces utilize smart surfaces to reflect and amplify signals, while also utilizing energy to support more coverage. RIS AI capabilities increase the intelligent adaptability of these surfaces, instead of passively reflecting signals based on real-time conditions.

5.7. Quantum Communication:-

Quantum communication provides ultra-secure data transfer with the use of photons. While it has the potential to be more secure than encryption methods, it is very expensive to implement on a wider scale, especially in government and military applications.

5.8. UAV/Satellite Communication:-
UAV/satellite communication offers connectivity to remote and underserved areas, utilizing drones and satellites to offer increased access for rural internet. It is also an important tool alternative for use in disaster response/helping to reach remote areas. However, both methods require an investment of time and money to ensure regulatory authorization before implementation 6. Recommendations and Future Research Directions for 6G Networks.

6. Recommendations and Future Research Directions for 6G Networks

6.1. Millimeter- and Terahertz-Wave Communication:-
Implement reinforcement learning algorithms to optimize testbed conditions (transmit power, location of antennas, channel allocation). - Develop solutions for more efficient spectrum usage and high data transfer rates. - Introduce ML algorithms to adjust signal fidelity and detract from interference.

6.2. Intelligent and Adaptive Protocols: -
Create intelligent handover protocols to offer uninterrupted connectivity to remote areas. - Apply predictive algorithms to improve connectivity and pre-emptive usage of network resources. - Apply context-aware systems that can be adapted to current network conditions.

6.3. AI-Driven Congestion Management Strategy:-
Apply NLP to analyze the data collected from the network to identify traffic congestion. - Implement traffic shaping and rerouting. - Identify analytics containing predictive algorithms for rapid capacity planning.

6.4. Low-Power Hardware and Sustainable Networks: -
Create energy-efficient components and low-power communication protocols.- Implement energizing harvesting technologies, i.e., kinetic and RF.- Introduce green networking, dynamic power usage, and energy-aware routing.

6.5. Encryption and Post-Quantum Cryptography Using AI: -
Research on homomorphic encryption to enable secure computation on ciphertext. - Develop lattice-based cryptography to ensure adequate protection against quantum attacks.- Enable information protection using AI-based encryption schemes.

6.6. Quantum Key Distribution: -
Develop QKD schemes that can be scalable for low-speed networks in the 6G networks. - Research entanglement-based secure communications protocols.

6.7. Ultra Reliable Low Latency Communication (URLLC):-
Development of protocols and standards, e.g., 5G NR URLLC and IEEE 802.1 TSN. - Research NOMA (Non-Orthogonal Multiple Access) for ultra-efficient communication in dense networks. - Provide low-latency, reliable communication with URLLC for industrial and health applications.

7. Conclusion
6G will take wireless communication to the next level, bringing ultra-fast speeds, near-zero latency, and AI-driven automation. It will transform industries like smart cities, healthcare, and autonomous systems, making connectivity more efficient and intelligent.

However, with these advancements come security risks, including data privacy threats and network vulnerabilities. To tackle these challenges, technologies like post-quantum cryptography and AI-based security will play a crucial role. Core technologies such as terahertz communication, ultra-massive MIMO, and quantum communication will drive 6G forward, but issues like high infrastructure costs and spectrum management must be addressed. Future research should focus on improving network efficiency, AI-powered congestion control, and stronger encryption methods. Collaboration between researchers, industries, and policymakers will be key to building a secure and reliable 6G ecosystem, paving the way for a more connected and intelligent future.

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